REPORT R-1876

ENVIRONMENTAL CRITERIA AND SIMULATION METHODS RESEARCH STUDY

by

MAURICE H. SIMPSON
DAVID ASKIN

December 1967

UNITED STATES ARMY
FRANKFORD ARSENAL
PHILADELPHIA, PA.

46

REPORT R-1876

ENVIRONMENTAL CRITERIA AND SIMULATION METHODS RESEARCH STUDY

by

MAURICE H. SIMPSON
DAVID ASKIN

AMCMS Code: 5027.11.701
DA Project No.: 1V025001A622

December 1967

QUALITY ASSURANCE DIRECTORATE
FRANKFORD ARSENAL
Philadelphia, Pa. 19137

ABSTRACT

The primary function of development and testing of Army materiel is to ensure that materiel scheduled for worldwide use satisfies minimum operational, technical and safety requirements in all types of environments and troop operational employment. Accordingly, design and test criteria must provide factual bases for technical doctrine to support operational objectives and improved combat capability.

This research program provides such factual bases. It does so by employing systems approach and operations analysis techniques applied to a viable environmental situation to develop environmental criteria and simulation methods. A model is developed that is devoid of arbitrary factors and is, thereby, realistic to natural environments of field and storage (standby) operations. Systems concepts are used to encompass the effects of multi-environmental complexes. Artificial and psuedo-environmental concepts are removed so that better correlation of laboratory testing with field performance is made possible. Criteria developed by this research are therefore appropriately precise and accurate for liklihood, margin for error, and risk (uncertainty) involved in the decision process.

Fundamentally underlining this research approach is the concept that hardware failures are always sysmptomatic of disorder in a particular dynamic system. Emphasis is on the constructive method of research wherein it is considered that an event is always the result of an interaction of several coexisting factors, and that hazards are not haphazard but exhibit patterns that can be identified. The event is studied as a whole, then the operative factors are gradually sorted out by a series of increasingly precise approximations. Overall relationships are maintained intact, correctly placed in relationship with each other and held in contact, yet they are differentiated. The net result is an "up-and-down" picture of nature's environmental system and its effects on materiel performance, leading to development of realistic environmental criteria and simulation methods.

FOREWORD

This report covers the statement of the problem, objectives, and performance requirements for DA Project 1V025001A622, "ENVIRONMENTAL CRITERIA AND SMULATION METHODS RESEARCH," Program Element 6.21.50.01.1, "ENVIRONMENT." Primary agency conducting these investigations is Frankford Arsenal, Philadelphia, Pa.

Supporting agencies have been USAMUCOM and USATECOM establishments (Picatinny Arsenal, Aberdeen Proving Ground, White Sands Missile Range, YUMA Test Center, Dugway Proving Ground, Tropical Test Center (Panama)), and Natick Laboratories.

Not-for-profit institution support has been Stanford Research Institue and Soutwest Research Institute; university support has been New Mexico State University; and contractor support has been American Power Jet Company.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

Nothing is more frustrating to a land combat commander than to have equipment failure halt his forward movement. Especially is this true when he has been informed that the equipment is most reliable, as attested, affirmed, and reaffirmed by batteries of tests and certifications by supporting services and suppliers. When it happens too often, anything his suppliers tell him thereafter is critically and severely questioned.

Such is the situation in the Army today. Too often, the commander and his staff planners are given "numbers," called "reliability," which are supposed to be all-pervading assurance that his troubles are over. These numbers are expressed in such terms as "MEAN TIME BEFORE FAILURE," or "PERCENT PROBABILITY OF PERFORMANCE AT PERCENT CONFIDENCE LEVEL." What the commander wants is an answer to . . . "When I send my troops out tomorrow to force 'objective X,' will the equipment do the job?" Instead of getting "Yes/No," he gets the "numbers" with which he is expected, somehow, to extract his needed assurance. Then, on top of that, despite "high numbers" given him, the equipment fails! No wonder the situation becomes chaotic.

The commander needs a "handle" he can grasp and use. Not only that, the handle must have a label in his own "language."

It is well known that information about the conditions of the physical environment is a fundamental requirement for practically all military activities. Environmental conditions which exist in any area of operations have dominating influence on planning, on logistical support, and on successful implementation. Furthermore, information about the conditions of the physical environment required for the design and testing of materiel must be determined by the probable conditions in which the product will be employed. As a consequence, phases of design, test, and evaluation must be based upon a model that is reasonable - one that approaches reality; otherwise, results of testing and evaluation show only that the design can produce results that are within the arbitrary artificial conditions which were established.

Present "reporting of reliability" and the philosophy and status of materiel design and testing as now practised by the Army, are singularly based upon such "artificial conditions." As such, much grave uncertainty is prevalent in the "management of reliability" of Army's materiel. It is evident that statistical inferences are invalid because of unrealistic bases on unrealistic models, as demonstrated by field failures. Even so, it is inherent that the planner (as well as the technologist) wants his materiel neither to fail nor to be overdesigned.

In research, engineering, and test and evaluation of Army's weapons systems and munitions, environmental effects have been heretofore treated as single environment problems - one-at-a-time; e.g., temperature test alone; then humidity test; then salt fog test; then sand-and-dust test; then ozone test; etc.

The real situation is that Army's operation weapons systems undergo a multiplicity of environmental stresses, concurrently and sequentially. Climate and use impose such conditions upon the soldier, his weapons, and his supporting services. The environmental technologist has been aware of the "real" situation, but has been unable to effectively cope with it because of the complex interaction effects caused by multivariate multiplicities which were not completely understood and could not be effectively described or simulated. Net result has been the low-order correlation of design-test criteria with the real state of natural environmental effects.

"One-by-one" criteria for laboratory testing, and the attempt to "fix" the situation by testing to psuedo-selection and arbitrary combinations of environments easy to perform have been judgement factors imposed for practical reasons. It is much easier to count than describe (and, preferably, one thing at a time) a common defect of statistical analysis and reliability engineering. Reality of the environmental situation, however, poses a complex of environments in an interactive situation.

What is needed is a way to "handle" the interaction effects of more than one environment, heretofore mostly undefinable (and, thus, unstatable) because of the complexity. A "key" is missing. The equipment developer and the environmental specialist have done the best they could with what knowledge they had and could understand. In the meantime, equipment failures have been prevalent in the field of operations. As a result, authenticity of reliability and confidence ratings have been severely questioned by the user. Arbitrary rerating and backing-off have not solved the problem.

DISCUSSION

The research method developed in this report and the results obtained therefrom will supply the missing "key" to the environmental criteria and simulation methods problem. It considers the physical environmental situation to be a casual behavior situation. Fundamentally underlining this situation is the consideration that hardware failures are always symptomatic of disorder in a particular dynamic system.

The explanatory model is that there is an environment composed of several coexisting factors whereby any or all of the factors can affect susceptibility to change in performance characteristics or the potency of the agent causing the change. In other words, one environment can or does affect another environment, and it is the agglomeration of all environments that affects equipment performance. The central problem, then, becomes one in which relevant interrelated and interacting variables need to be identified and central relationships quantified.

The physical environmental situation, therefore, is one in which there are multivariate aspects of multienvironmental elements, a probability that such aspects occur, and the power of effects when they occur together. In such a complex situation, the most powerful tool that can be used is <u>operations analysis</u> - the system concept of . . . input-transform-output. . . which, by its nature, is pervasive in awareness of interrelatedness interwoven between several inputs, between inputs and outputs, and between transformation functions and effectiveness of output.

When operations analyses techniques are applied to the physical environment situation problem, it is found that there is a synoptic situation that clearly indicates a taxonomy of <u>climates</u> enveloping only <u>significant elements</u> which can be clearly defined. Furthermore, when these "climates" are considered as sets, and the significant climatic factors as elements of the sets, then any treatment of the set, of necessity, includes treatment of interactions and synergism of the elements of the set.

Thereupon, the environmental situation model for Army materiel is a "climate" consisting of no more than six significant environmental factors which are: (1) temperature, (2) humidity, (3) precipitation, (4) wind, (5) contamination, (6) radiation. Using this model as a <u>means-end schema</u>, problem areas are then clearly pointed out and problem requirements and solution requirements clearly defined, which could not be done before. As a result, ambiguity has been obviated for the technologist and he can "see" and include the significant and necessary interrelationships and interactions. Thus, the criteria and test methods developed therefrom can only produce high correlation with actual field operational and storage (standby) conditions.

As a result of this research, design and test criteria developed therefrom will provide: factual basis for technical doctrine, as appropriate; verification of reliability and maintainability; assesment of quality; and identification of requirements to support operational objectives. Furthermore, criteria will be in terms of objectives and will be appropriately precise and accurate for evaluating the liklihood, uncertainty, and margin for error, necessary for the decision process and deliberate appraisal of hazard. In addition, the format is suitable for computerization.

As a result of this research approach, it is also demonstrated that system engineering of the problem can be used to "manage" applied research objectives of non-hardware programs as well as hardware programs.

RESEARCH OBJECTIVE

Program objective is to transpose natural climatic effects and influences upon performance of military materiel into realistic criteria for design and laboratory environmental testing. Specifically, it is to develop realistic criteria, test methods and test procedures that adequately correlate with actual climatic field operational and storage conditions. As such, it is to preclude repetition of past judgment errors that have required "fixes," and have contributed to limiting military operations in geographic areas of concern. Furthermore, it is to establish greater confidence that Army's materiel does, in fact conform with its reliability rating and other specified military characteristics (such as physical, operational, functional, environmental, maintenance, and safety requirements).

RELEVANCE

This research program is in direct support of Land Warfare Operations in accord with established Combat Development Objectives Guides. Furthermore, the program is in direct support of Southeast Asia and any other potential geographical operational areas of concern through maintenance and improvement of Army's land mission readiness and combat strategic advantage, and complements supporting research to vehicle mobility, equipment engineering, applied research projects, and national and international military standardization.

Recognition of need for such information is established in Army regulatory documents, emphasized particularly by requirements of AR 70-10, "Army Materiel Testing;" AR 705-5, "Research and Development of Materiel;" AR 705-15, "Operation of Materiel under Extreme Conditions of Environment;" and AR 705-25, "Reliability Program for Materiel and Equipment."

Essence of the research is directed to need for improvement in communications with the military logistician and operations planners regarding materiel environmental capability and capacity, ease of maintenance, and reliability aspects. Scope of this research is also related to such standards as MIL-STD 210A, "Climatic Extremes for Military Equipment," and MIL-STD 810B "Environmental Test Methods for Military Equipment."

The program is particular [illegible] the needs of Army for mission accomplishment in armament and munitions aspects of land warfare operations in accord with the following Combat Development Objectives Guide (CDOG) references: CDOG 111b (3) - "Land Warfare Operations, General Organizational Objective;" CDOG 112a (2) - "Land Warfare Operations, General Materiel Objective, Basic Consideration;" and CDOG 210a - "Infantry Operations, General Operation Objective."

This research program also supports and complements other Army research, development, engineering, and standardization activities; such as: vehicle mobility; equipment engineering, development and design; applied research projects; and related national and international standardization activities. The appendix includes a list of such support.*

*This research program also supports and complements the National civilian effort in combating corrosion, pollution, and other degrading effects of the environment.

ELEMENTS OF THE PROBLEM RE MILITARY OPERATIONS

Forde and Schierbrock* stated that . . . . "Information on the conditions of the physical environment is a fundamental requirement for practically all military activities. The conditions which exist in an area of operations can have a dominating influence on the planning of proposed operations and for logistical support which must be supplied." Thus, plans for personnel, supplies, equipment, organization and training, movement and combat, as well as the design and test of materiel, tactics, and techniques, have to be based on information concerning the conditions which may be reasonably expected during combat operations in the selected areas.

Furthermore, it was stated that "Information on the physical environment which is required for the design and test of materiel, tactics, and techniques must be determined by the probable conditions in which the product will be employed. A certain degree of generalization is possible, yet reasonable limits must be established for the conditions with which the product must cope. The phases of design, test, and evaluation must be based upon a model which is reasonable and one which approaches reality. Otherwise, the results of testing and evaluation show only that the design can produce results within the artificial conditions which were established."

Present status and philosophy of testing and design, and the reporting of reliability, as practised by Army today, are singularly based upon such artificial conditions.

It is necessary to recognize that determination of significant elements of the physical environment for the military user requires two parallel studies conducted simultaneously - one, of the conditions, effects, and influences of the environment, and the other, of the component elements and activities of the military actions which are affected by the physical environment. Points of contact of the two studies occur in the consideration of effects and influences, the selection of items of significance, and in the establishment of methods of measurement and presentation of the environmental information.

*See Item 1, BIBLIOGRAPHY.

Study of physical environment establishes elements and characteristics of the factors of terrain, climate, and vegetation. Subsequently, effects which are produced by these characteristics, operating both singly and in combination, must be identified and a method devised to measure their significance and intensity at various scales or degrees of generalization. The system of classification and the methods of measurement must be useful to all levels of the military activities for both operational employment and in research and development of materiel and method. Furthermore, the system of classification as a communicative device must avoid contributing irrelevant information (noise) that masks significant features.

Study of effects and influences of environmental conditions upon military activities needs to be based upon analyses of military functions, tasks, and activities. Each component is investigated in terms of need for information on environment essential to the success of the particular military action. In this manner, identification is made of those elements and characteristics of the physical environment which are significant to the specific military activity or task. Test of the system of classification and measurement of characteristics and effects must be a continuing and concurrent activity to ensure suitability of the system for military use.

After establishing the elements of military functions, tasks, and activities, the investigation of environmental influences must be made. An immediate problem is encountered because of the differences in specific environmental qualities, as stated by the environmental specialist and by the military user of the information. The elements of the physical environment are usually measured and expressed by the environmental specialist in a form suitable for numerical recording, while the military user expresses the environment in terms of features, or combinations of environmental elements.

However, this disparity is not unresolvable, since each of the features can be described in terms of one or a combination of characteristics. At the present time, work has not progressed sufficiently in direction, definition, or content to permit transition from environmental characteristics to statement of the feature which is of importance to the military user. What needs to be done is to translate environmental characteristics into related terms affecting combat effectiveness and mobility, and into value engineering and value analysis of materiel as a component of an integrated system. By these means, then, there will be no conflict in terminology and classic sequence of action in the military process of estimating the situation, decision, development of a plan, and implementing the planned action.

ELEMENTS OF THE PROBLEM FOR THE ENVIRONMENTAL SPECIALIST

Army's land warfare mission is logistical as well as operational. The environmental specialist has to be aware that he is a purveyor of information that is to be usable for decision-making in tactical situations. Thus, in order for him to gain better knowledge about the degree of predictability, controllability, and damage effects of the environment, it is most appropriate for him to study the features of the environment with a two-prong attack: (1) the properties of the environment, and (2) the effects of the environment.

Environment, by definition, must be considered to be an ambient condition. As such, it is appropriate to consider the accomplishments of other "environmentalists," such as in biology, human behaviorism, cybernetics, and systems engineering. The most cogent aspects to be aware of are that there are coordinative relationships involved where there are interacting and interfacing situations, and that total effect is not a simple summation of parts.

Natural environmental-effects approach has to differentiate and be particularly precise about effects caused by surrounding conditions that may pervade, but are not inherent within - or caused by - the artifact itself. Considering climate to be a special grouping, or class, of environmental properites (e.g., tropical, as warm-humid; desert, as hot-dry) is valid for the military planner as long as the climate (class) has been sufficiently defined by its elements (e.g., temperature, humidity, rain, snow, wind, sunshine, etc.).

Evaluation based upon singular effects of the individual elements - one-by-one or in some psuedo-combination - is invalid because of exclusion of interaction effects. Chamber testing under single environments, coupled with statistical plotting and analysis, has been of little help. Synergetic synthesis and simulation are powerful methodologies for attack of the problem of interactions, especially when the model is climate as a class (set). When doing this, consideration must be emphasized about man's interference and effects on a climate; i.e., his manipulating and altering relationships with susceptible environmental features. Also, one must not forget shock and vibration inputs, such as caused by travel across rough terrain, firing stresses, and explosion ambients in combination with climatic factors.

Thus, for the environmental specialist, the features of the natural environment encompass two particularly pertinent differentiations; i.e., determination and definition of environmental (1) characteristics as elements of a class (set) considered as a climate; and (2) effects as coordinative aspects of a multivariate situation. Furthermore, the features must fit the situation of evaluating capability relative to requirements for military activities in terms of expectation and risk. Such a fit, then, makes it possible to establish correspondence between possible outcomes of the situation and possible decisions to be taken relative to risk involved.

What is needed is a definition of criteria, in terms of the ambients, that will have effect on equipment performance needed for military activity, and the performance rating of the equipment relative to those same criteria. As such, then, the physical environmental criteria must be presented as features in terms of what the military planner can use, specify, and evaluate for his needs as a better way to utilize environmental science and technology in the national interest because it is a more useful description of the environment.

In other words, the environmentalist's approach needs to be changed from a "two-bet" to a "one-bet" situation. "If the danger comes, I bet that I can handle it," is a one-bet situation. "If the danger comes, I bet that I can handle it, but I also have to bet that the danger has low probability," is a two-bet situation. The latter statement puts the operations planner at a disadvantage in terms of preparation - the position he is in now relative to environmental criteria and equipment performance.

RESEARCH APPROACH

Focusing The Problem Onto Effects (The Model)

Explicitly, there are multivariate aspects of multienvironmental elements envoloped in an environmental situation. Coupled with these are the aspects of probability that individual environmental elements occur and the power of effects when they occur together. In such a complex situation, a powerful tool that can be used is Operations Analysis - the system concept of . . . input-transform-output. . . process - which is pervasive in awareness of interrelatedness interwoven between the several inputs, between the inputs and the outputs, and between the transformation function and effectiveness of outputs.

It is most helpful in all problem-solving situations to diagram the situation. Figure 1 is such a diagram which is a fundamental picture of the overall environmental situation.

System-problem-solving techniques formally encompass the following requisites:

(1) Indentification of variables.

(2) Development of relationship between variables (modeling).

(3) Preparation of an appropriate data base.

(4) Use of an algorithm.*

It is obvious from these requisites that there is a definite ordering of events.

The problem situation is such that there is a climate consisting of an envelope of natural environmental factors of the natural ambient condition. Conceptually, the envelope is depicted in Figure 2 with the environmental factors in generic classification.

Because there is a two-way functional relationship between factors of the environment and effects of the environment, mapping techniques are appropriate.** Such a map is Figure 3, which considers each extreme climate to consist of an envelope of elements

---

*The assumption is that algorithmic methodology uses step-by-step rules of procedure to attain final solution.

**The notion of <u>function</u> is an extremely useful one in science. Mapping is synonymous for "function" and describes the function.

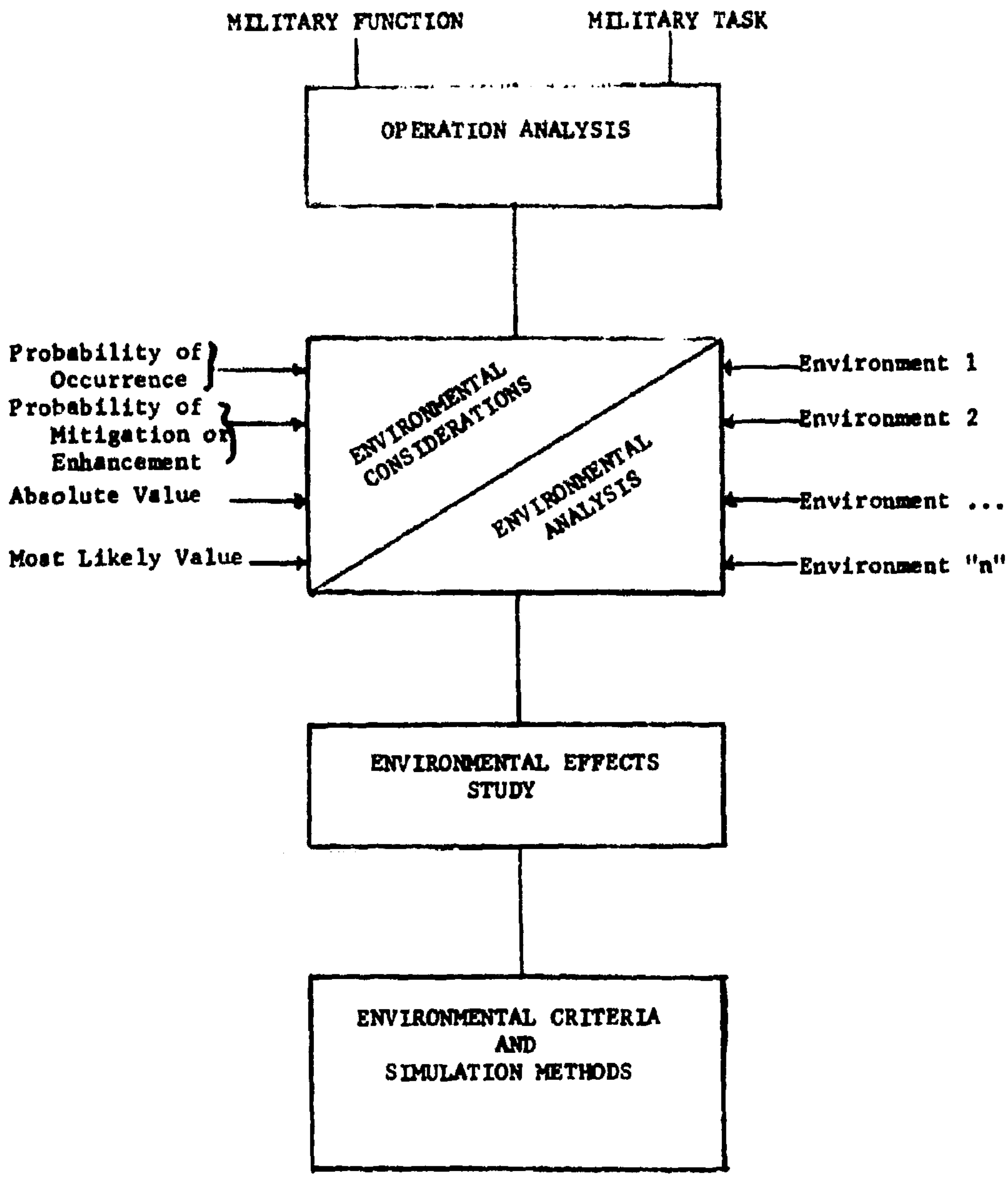


Figure 1. Environmental Situation Diagram

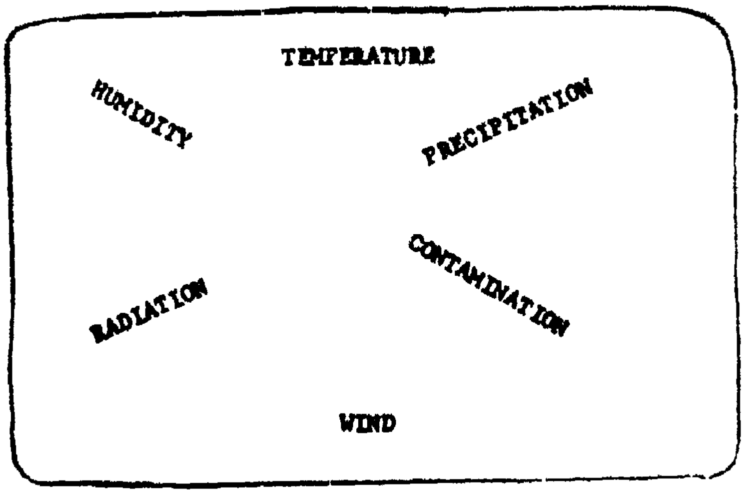


Figure 2. Environmental Envelope of a Climate

which are defined as specifics at level #2. As such, Figure 3 is a model of the situation.

Logic of this model is such that environmental information (requirements) "E" consists only of the significant occurrence and definition of the features of the environment that must be considered. Fundamentally, it states that features cannot be defined until (1) climate has been categorized; (2) elements of the climate have been defined in their severities; and (3) combined and sequential effects of the elements have been assayed.

Mathematically, the logic is expressed as follows:

<u>Level #1.</u> All E_{1j} are mutually exclusive: i.e.,

$$E_{11} \cap E_{12} \cap E_{13} = \varnothing, \text{ null set.}$$

<u>Level #2.</u>

$$E_{2j} = \{ E_{1j} \}$$

i.e., set of all admissible elements.

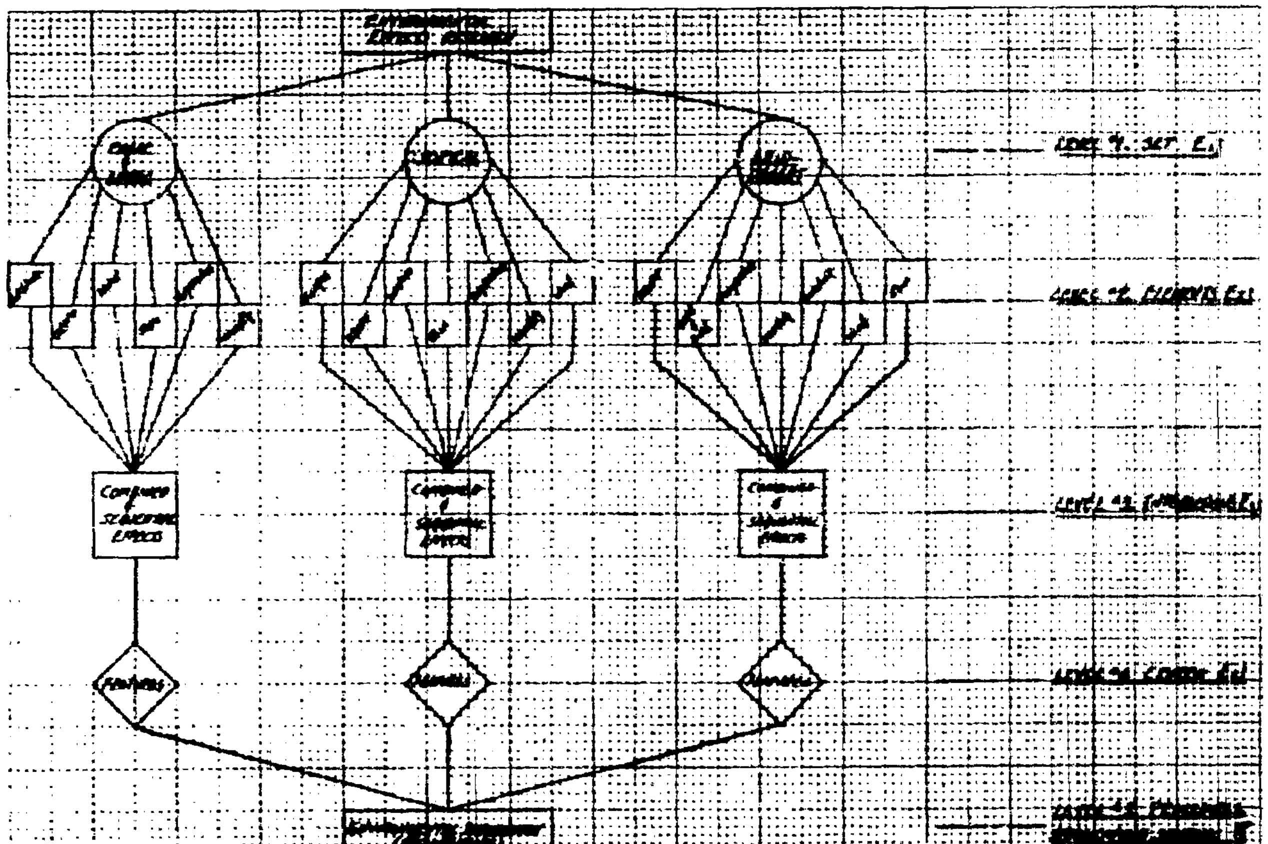


Figure 3. Mapping of Environmental Criteria and Simulation Methods Research

Level #3.

$$E_{3j} = a_j \bigcup b_j \bigcup c_j \ . \ . \ . \ \text{of } E_{2j}$$

where a_j, b_j, c_j . . . are single environments, such as temperature, humidity, etc.

Level #4.

$$E_{4j} \subset E_{3j} \subset E_{2j} \subset E_{1j}$$

i.e., the event E_{4j} implies the event E_{3j} occurs; the event E_{3j} implies the event E_{2j} occurs; the event E_{2j} implies the event E_{1j} occurs.

Level #5.

$$E = E_{41} \bigcup E_{42} \bigcup E_{43}$$

i.e., the event E occurs whenever either the event corresponding to E_{41}, the event corresponding to E_{42}, or the event corresponding to E_{43}, or any or all occur.

Such is the means-ends schema. Objective effort is to be comprehensive of the following facets.

Facet #1. Definition of the "real" environment is to be one that includes only those significant environmental factors and ranges that comprehend a mutually exclusive situation, called a climate, which distinguishes it from any other climate.

Facet #2. Refinement of environmental factors of a climate into criteria that comprehend effects as complex features involving multivariate interactions.

Facet #3. Comprehending environmental effects with equipment, thereby transposing effects criteria into specifications and standards for engineering and laboratory simulation and test procedures.

Facet #4. Comprehending environmental effects with equipment, thereby transposing effects criteria into features that can be developed into decision criteria and decision requirements; e.g., transposing a measurement number (e.g., reliability) into a decision factor.

Focusing the Problem into Tasks

Because of the complexity of the environmental problem and involved facets, there is need to reduce the problem to a finite sequence of sub-problems as tasks. The reduction procedure, in part, has already been accomplished in the development of the model (Figure 3) and follows the model. In essence, the reduction is into four groupings of tasks, which are: (1) climates, (2) elements, (3) combinations of elements, and (4) consolidation into criteria.

Climate Tasks

Because E_{1j} (Figure 1) is mutually exclusive, it follows that each climate, therefore, is a separate task, as follows.

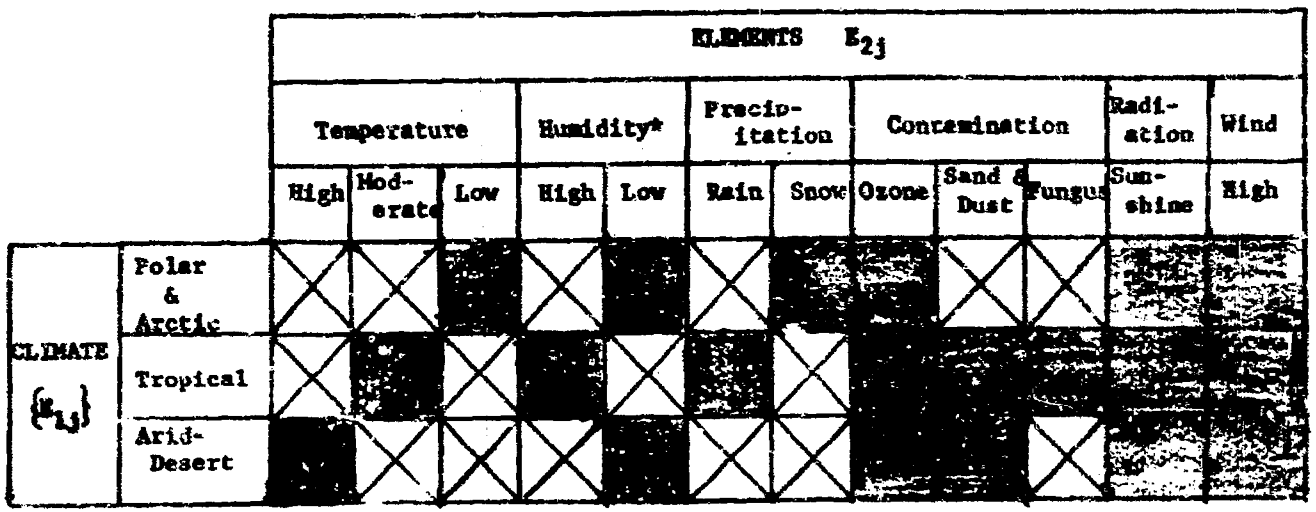
Task	Definition
Polar and Arctic	$\{E_{11}\}$
Tropical	$\{E_{12}\}$
Arid-Desert	$\{E_{13}\}$

Temperate climate is not considered because of lack of severity in its elements and combinations of elements.

Element Tasks

Elements of the classes (climates) $\{E_{11}\}$, $\{E_{12}\}$, $\{E_{13}\}$ could be considered as subtasks under the general tasks, however, it is more desirable to consider them as separate tasks, as explained in Figure 4, which is a matrix as an array of elements of each climate qualitatively arranged.

The parameters of temperature and humidity are interrelated and specific to a climate (e.g., low temperature with low humidity perculiar to Polar Arctic; high temperature and high humidity



*Humidity measured in total water vapor content.

NOTE: Shaded blocks show occurrence and order of severity.

Figure 4. Matrix of Elements of Climate $\{E_{1j}\}$

peculiar to Arid-Desert; and moderate temperature and high humidity peculiar to Tropical). Also, in terms of greater severity, snow is unique to Polar and Arctic, and fungus is unique to Tropical regions, respectively. Such uniqueness is not true of other elements. For instance, sunshine and ozone are prevelant to all climates. Then there is the causal situation where one element is caused by another; e.g., sand and dust caused by wind; ozone caused by sunshine. Also there is the situation whereby there can be either rain or sunshine, but not both together. In other words, because of such situations and/or characteristics, separate tasks should be assigned to research of the following elements.

Task	Definition
Sunshine	element aj of E_{2j}
Rain	element bj of E_{2j}
Ozone	element cj of E_{2j}
Sand and Dust	element dj of E_{2j}

Combinations of Element Tasks

The matrix arrangement (Figure 4) also points out possible interaction effects caused by combinations of environmental elements of a climate. In functional form, the possible combinations are made up of at least four elements in interaction at any time, in at least two different situations that could have a different order of severity, as shown in Table I.

Because of this multivariation of effects of multiple elements, it follows that a separate task should be made of the following.

Task	Definition
Combined and Sequential Environments	E_{3j}

Table I. Combinations of Elements in a Climate
(E_{3j} for E_{1j})

E_{1j}	E_{3j}
Polar and Arctic Effects	$f_1 (e_t, e_h, e_s, e_w)$
	OR
	$f_2 (e_t, e_h, e_o, e_{ss}, e_w)$
Tropical Effects	$f_1 (e_t, e_h, e_r, e_w, e_f)$
	OR
	$f_2 (e_t, e_h, e_o, e_{ss}, e_w, e_f)$
Arid-Desert Effects	$f_1 (e_t, e_h, e_o, e_{ss}, e_w)$
	OR
	$f_2 (e_t, e_h, e_{sd}, e_w)$

where: $\left.\begin{matrix} f_1 \\ f_2 \end{matrix}\right\}$ = function of

e_f = fungus effect

e_h = humidity effect

e_o = ozone effect

e_r = rain effect

e_s = snow effect

e_{sd} = sand and dust effect

e_{ss} = sunshine effect

e_t = temperature effect

e_w = wind effect.

Consolidation into Criteria Task

Finally, because E (Figure 3) is inclusive and comprehensive of all features (criteria) of E_{4j}, it consolidates information engendered as a totalizing effect for each climate E_{1j} and for all climates E_{1j}, therefore E is a separate task as follows.

Task	Definition
Environmental Information (Cataloging and Dissemination)	E

In addition, in connection with E but not wholly E, there is requested support to the Army Engineering Handbook Series. Input will consist of environmental engineering information attained by this research program and assigned as a separate task.

In summary, Table II lists the tasks in an arbitrary order to accommodate the program.

Table II. Tasks to Accommodate Environmental Criteria and Simulation Methods Research

Task Number and Title	Identification to Model (Figure 3)
Polar and Arctic Test Procedures	Level #1 $\{E_{11}\}$
Ozone Test Procedures	Level #2, element of E_{2j}
Sunshine Test Procedures	Level #2, element of E_{2j}
Rain Test Procedures	Level #2, element of E_{2j}
Sand and Dust Test Procedures	Level #2, element of E_{2j}
Tropical Test Procedures	Level #1, $\{E_{12}\}$
Development of an Environmental Information and Cataloging System	Level #5, E

Table II. (Cont'd)

Task Number and Title	Identification to Model (Figure 3)
Effects of Combined and Sequential Environments	Level #3, E_{3j}
Army Environmental Handbook Series	Related to E
Arid-Desert Test Procedures	Level #1, $\{E_{13}\}$

Focusing Research Tasks into Performance

System procedure is not only useful because of the complex interrelationships that can be handled, but also for technical review and technical fiscal reporting and evaluation, and it is especially relevant to Policy Evaluation and Review Techniques (PERT) methodology. Accordingly, the following algorithm (Figure 5) is designed to comprehend performance for each task and the total program.

State Problem (I). The statement of the problem consists of the input of the input-transform-output system process, and it is to cover objectives and relevance of the particular task on hand. Particularly significant at this step is that it be firmly established that there is a problem, that the problem is unique, and that it exists as affirmed by its various elements.

Examine "Real" Environment (II). At this point the factors of the "real" environment are to be established, where the real environment is to consist of those elements and/or interrelations of elements that are known and established to have effects on equipment performance. Effect is to imply not only degradation, but also improvement.

Restate Problem in Terms of "Real" Environment (III). This is the model building point whereby there is description of the

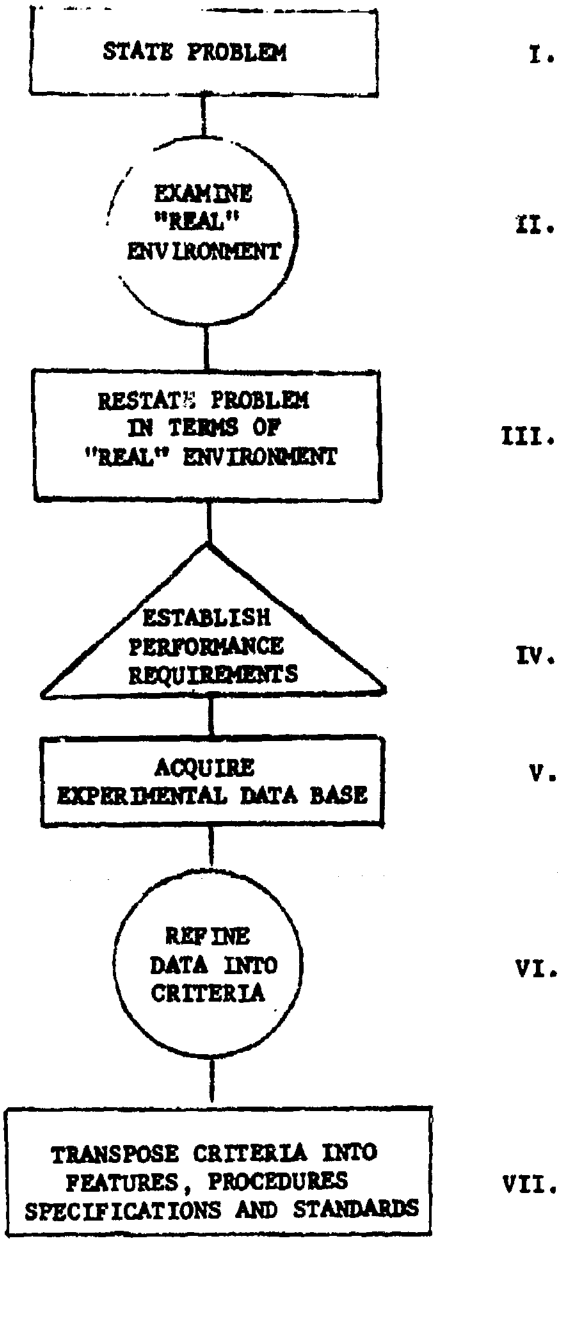


Figure 5. Algorithm for Program Performance

situation in only essential features, in order to filter out "noise" from obscuring the problem. Mathematical description will employ set terminology, wherein it will be established that the set S (climate) consists of a body of properties dividing S into subsets, and having a measure function for any set so obtained and a probability density function.

Establish Performance Requirements (IV). This is the point of postulation wherein hypotheses are established and method designated and wherein questions can be answered in conformance with the model of the situation. Task performance relative to an entire set (climate) or an element of a set are to have points of overlap and points of interrelationship. Scientific inference and design of experiments, as two powerful tools, will be established for requirements.

Acquire Experimental Data Base (V). Data are to be acquired from several sources, such as established creditable macro- and micrometeorological natural environment information, published in the scientific literature as natural environment data. Where there are gaps in the information, field and laboratory measurements will be acquired to establish data relative to natural characteristics and effects.

Refine Data into Criteria (VI). Analysis of data will result in an environmental envelope for each climate. This envelope will consider and be shown in probability density format, expressed as mean/median and peak values and degree of expectation. Also, where baseline data trends and evaluation clearly indicate empirical relationships, such relationships will be pursued to develop curves with deterministic properites. Furthermore, where criteria have been developed, they will be tested in the environmental laboratory to establish facilities design criteria and to establish and test simulation methods.

Transpose Criteria into Features, Procedures, Specifications, and Standards (VII). Technical interim and phase reports will be published to disseminate the criteria as information to engineering and planning communities. Further imparting of the information will be through participation as members of standing and ad hoc committees for review and modification of Specifications, Standards (such as MIL STD 810, "Military Standard for Environmental Test Methods for Aerospace and Ground Equipment"), and Army Regulation (such as AR 705-15, "Research and Development of Materiel, Operation, of Materiel under Extreme Conditions of Environment"), and the like. There also will be inputs into the Army Environmental Handbook Series.

As part of the transposition of the criteria, the criteria will be put into a useful form adaptable to cataloging and dissemination in an information system that will fit the requirements to answer questions and correlary questions of the military operations planners and logisticians. In all aspects, transposed criteria will be suitably precise and accurate to base technical and operational decisions that entail likely occurrence, margin for error, risk of failure, and be suitable for computerization. It is inherent that the military planner (as well as the technologist) wants materiel that will neither fail nor be overdesigned.

This algorithm applies equally to performance of each individual task and to performance of the overall program. Performance at these two levels will have several points of contact and will overlap. Technical reporting will be cognizant of such situations and will be accomplished where significant information will be most useful.

Figure 6 is a matrix which shows the interwoven and interrelated points of contact. Tasks are grouped as follows: those in the left column are climates which contain all the relevant elements, those in the right columns are either elements of a subset of one or more climates, or are operations on the set and subset.* Rows are the performance procedure.

Using the Figure 6 conception, then, progress and status of performance can be recorded, reported upon, and evaluated for each block (and each row), where each block, thus, includes the interrelationships, and each row the mode. Thus blocks and rows are checkpoints. Therefore, Figure 6 becomes the heuristic and modus operandi to follow for both management and technical performance of the Environmental Criteria and Simulation Methods Research Program.

---

*Set is a climate that includes all elements of the environmental envelope; subset includes only those elements that are specifically designated as unique tasks defined on page 15.

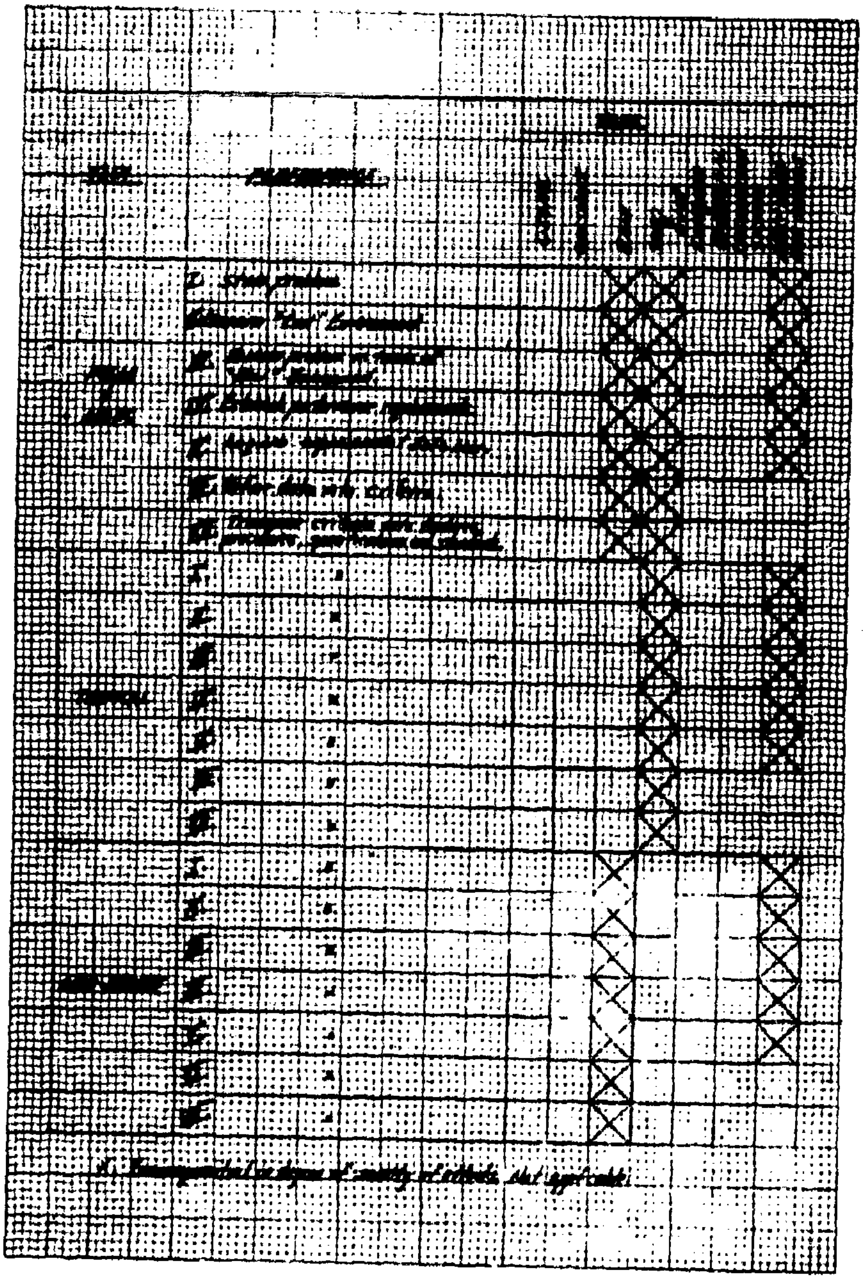


Figure 6. Matrix Showing Task's Interfacings and Interrelations

MANAGEMENT OF THE PROGRAM

Technical Management

Technical program review and analysis can be accomodated by using the matrix of Figure 6. The chart comprehends the entire program, as well as the step-by-step procedure of component tasks. Interim progress is exhibited by establishing percent completion of each of the individual blocks. Total interim progress is exhibited by summation of all of the individual blocks in the rows and columns of the area of interest.

For example: Evaluate each block to be a total possible "1.00" when 100% completed; then 35% completed will be equal to .35, 50% completed, .5, etc. If, for instance, blocks I, II, and III have been completed for the Polar and Artic-Ozone part of the program, but block IV is only 35% completed, block V is 50% completed and blocks VI and VII still remain to be accomplished, then progress for Polar and Arctic-Ozone part of the program is -

Block I	1 x 1 =	1.00
Block II	1 x 1 =	1.00
Block III	1 x 1 =	1.00
Block IV	.35 x 1 =	0.35
Block V	.5 x 1 =	0.50
Block VI	0 x 1 =	0.00
Block VII	0 x 1 =	0.00
Total		3.85

Total progress of the Polar and Arctic-Ozone part of the program would then be 3.85/7.00 = 55% completed.

Likewise, if there has been no performance yet for four of the tasks of the Polar and Arctic part of the program, then total progress for Polar and Arctic - all parts - would be exhibited by adding all of the blocks and dividing by 28; in this example, 3.85/28, or 13% total completion.

Progress for the total program matrix can be evaluated in the same way.

Cost Management

In previous budgetary estimates and command schedules submitted, especially in FY 60, 61, and 62, the total program estimate was 50 to 80 man-years of scientific and engineering effort. Breakout of this estimate is shown in Table III.

Table III. Estimate of Manpower Requirements

	Manpower Requirements (man-years)
1. Polar and Arctic Test Procedures	4 to 7
2. Ozone Test Procedures	6 to 8
3. Sunshine Test Procedures	6 to 10
4. Rain Test Procedures	4 to 6
5. Sand and Dust Test Procedures	3 to 6
6. Tropical Test Procedures	6 to 10
7. Environmental Information and Cataloging System	8 to 12
8. Effects of Combined and Sequential Environments	8 to 12
9. Army Environmental Handbook Series	1 to 2
10. Arid-Desert Test Procedures	4 to 7
Total Program	50 to 80

Sixty-five man-years is the midpoint for total program requirement. However, to use this as a norm for evaluating performance is unwise. It is well known from experience that logistic and hardware development cost functions (i.e., cost vs performance) are nonlinear. Especially is this true about research projects where it is better to base the cost of research performance on a range of input values.

Table IV is a breakout of estimated manpower and performance data for this research program which accomodates a range of values.

Table IV. Cost Assessment and Performance

Man-years	% Labor Expended Range	% Labor Expended Midpoint	% Expected Progress Range	% Expected Progress Midpoint
2	2- 4	3	2- 6	4
4	4- 8	6	4- 8	6
8	8- 16	12	5- 13	9
10	12- 20	16	8- 14	11
15	18- 30	24	11- 19	15
20	25- 40	32	15- 25	20
25	31- 50	40	28- 34	31
30	37- 60	49	32- 40	36
35	44- 70	57	33- 42	36.5
40	50- 80	65	35- 49	37
45	56- 90	73	39- 53	46
50	63-100	81	58- 70	64
55	69-100	85	59- 76	67
60	75-100	87	59- 77	68
65	81-100	91	65- 81	73
70	87-100	94	72- 84	78
75	94-100	97	84- 90	87
80	100-100	100	98-100	99

Figure 7 is the program cost function curve derived from the data in Table IV. This curve is the cost function Y = f(x) from which

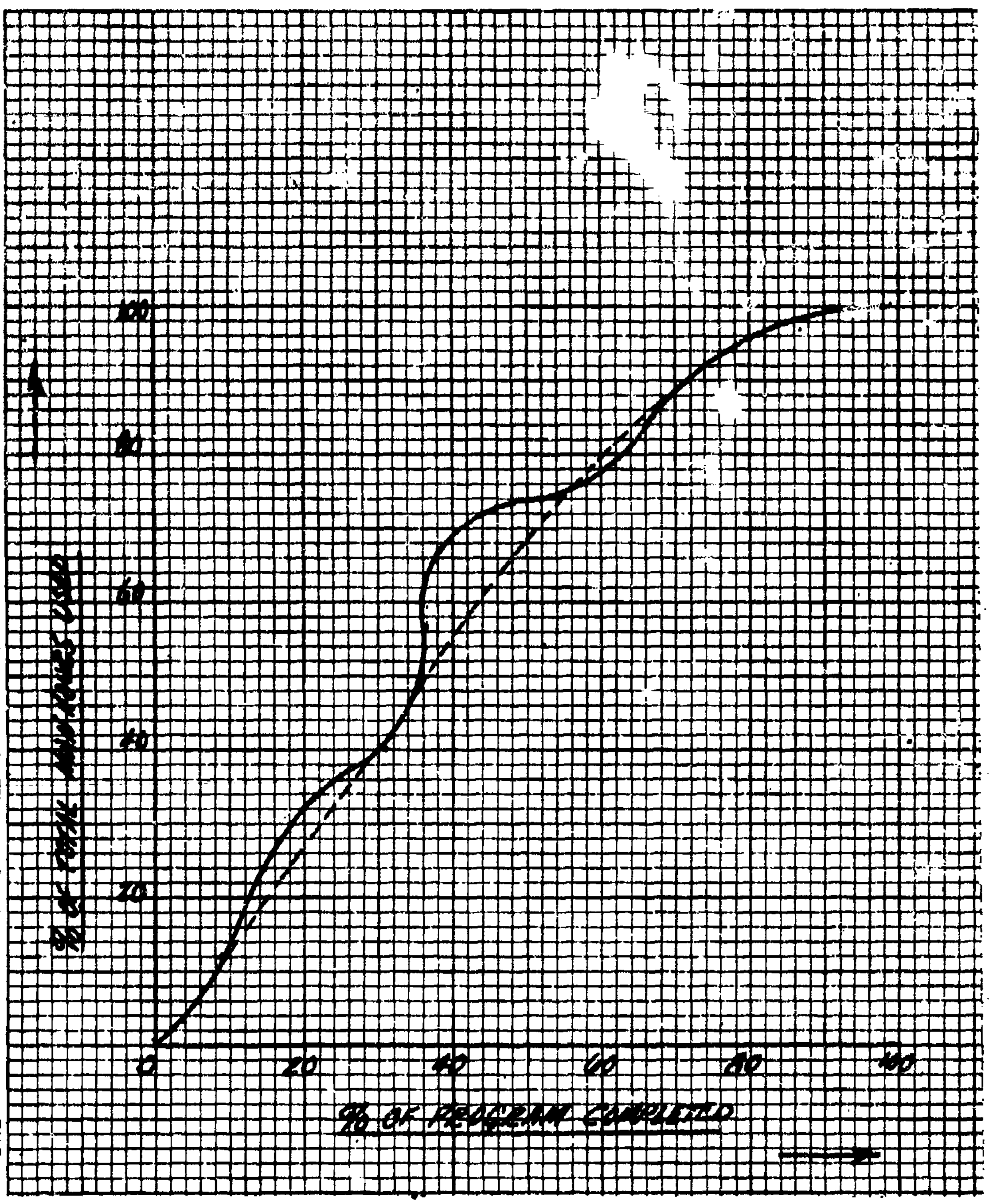


Figure 7. Program Cost Function Curve

progress can be evaluated. The abscissas are percent of program completed, and the ordinates are percent of total manpower used. This curve can be used to control (or estimate) performance.

As can be seen from Figure 7, the curve is undulating convex-concave. The beginning of the curve shows the effect of the "learning curve" situation. The heavy line curve is atypical to most cost function curves because it shows intuitive projection of research "stagnation" periods, or breakdown in rate of progress; i.e., deviations from the smooth "growth" curve are to be expected. Such periods are phenomena encountered in all research and need to be encompassed in estimating requirements (resources) to accomplish a research program and review of progress made. In this research program, the stagnation periods are expected to occur about 1/3 and 3/5 of the way through the program.

The broken-line section (Figure 7) shows a smooth overall curve, typical of a logistical cost function curve,* which can be described in the form of a power function curve, as -

$$Y = \frac{K}{1 + e^{A + BX + CX^2 + \dots}}$$

or as a polynomial curve, as -

$$Y = A + BX + CX^2 + DX^3 + \dots.$$

However, because of the atypical stagnation periods encountered in research, it is illogical to formulate such smooth curves initially from the estimating data. Nonetheless, as the project proceeds, a smoothing out procedure may be possible.

*See, for instance, "Formulating Analytical and Technical Estimates," (item 2 in the Bibliography).

CONCLUSIONS

As stated, the research method developed in this report and the results obtained thereform supply the missing "key" to the environmental criteria and simulation method problem. It considers the physical environmental situation to be a casual behavior situation. Hardware failures are always symptomatic of disorder in a particular dynamic system. One environment can or does affect another environment, and it is the agglomeration of all environments that affects equipment performance.

The design and test criteria developed as a result of this research provide: a factual basis for technical doctrine, as appropriate; verification of reliability and maintainability; assessment of quality; and identification of requirements to support operations objectives. The criteria will be in terms of objectives and will be appropriately precise and accurate for evaluating liklihood, uncertainity, and margin for error, necessary for the decision process and deliberate appraisal of hazards. The format is also suitable for computerization.

It is also demonstrated that system engineering of the problem can be used to "manage" applied research objectives of nonhardware programs as well as hardware programs.

APPENDIX

PROJECT SUPPORT
OF
ARMY RESEARCH, DEVELOPMENT, ENGINEERING, AND STANDARDIZATION ACTIVITIES

Relation to Development and Engineering

This project definitely supports Applied Research Category Projects 6.2, 6.3, 6.4, 6.5, and 6.7, concerned with vehicle mobility, equipment engineering and development, including design, It supports

Element 6.21.29.01.1 - Missiles
Element 6.21.41.0.1 - Combat Support
Element 6.41.12.12.1 - Electronic Warfare
Element 6.41.18 - Air Mobility
Element 6.41.18.06.1 - ACFT Support Fire Systems
Element 6.41.27 - Firepower other than MSL
Element 6.41.30 - Surface Mobility
Element 6.41.33.24.1 - General Combat Support
Element 6.51.02.06.1 - WS Missile Range
Project 1V027011A045 - Vehicle Mobility under Adverse Soil Conditions
Project 1V02701A049 - Ground Mobility Research
Project 1X332101D253 - DCSP Ground Environment
Project 1P650212D620 - Munitions Effect Support
Project 1A650212D623 - Instrumentation APB
Project 1X579191D393 - CEV 70
Project 1C024401A329 - Research in Methods of Test and Evaluation
Project 1C024401A109 - Corrosion Prevention & Specialty Comp.

Relation to Other Research

(1) This project supports and is supported by the following 6.21 Applied Research Projects:

Project 1V025001A129 - Environmental Research. This project includes the updating and revision of AR 705-15, which includes established environmental criteria.

Project 1V025001A130 - Cold Regions Research. This project includes military operational capabilities under extreme low temperature and the evaluation, establishment, and definition of environmental criteria.

Project 4A025001A890 - Lunar Base Research. This project includes basic environmental criteria typical of the extra-terrestrial environment.

Project 2M025001A724 - Studies of Extreme Regions. This project includes evaluation and classification of natural environmental conditions in extreme world areas.

Project 1F121401A237 - Air Vehicle Research Handbook. This project includes environmental design criteria with reference to air vehicle operational capabilities.

Project 1V021701A047 - Transportation Environmental Studies. This project includes natural environmental criteria wherein Army aircraft are expected to operate.

Project 1M521801D264 - Automotive Components Development. This includes the operation of components under natural and induced environments.

(2) Category 6.11 Research. Any research which leads to a better understanding of the natural and induced environments wherein Army personnel, equipment, and components must operate, provides valuable input to this project. It is supported by basic environmental criteria studies under Project 2M014501B52B, "Terrestrial Sciences Research," and Project 1L013001A91A, "In-house Laboratory Independent Research." In addition, it is supported in part by Project 1V014501B53A, "Research in Atmospheric Sciences."

Relation to Other Government and National and/or International Agencies

All research conducted and sponsored by other agencies, both service and not service connected, oriented toward the solution of problems associated with operations of men and equipment under extreme natural and induced environmental conditions contributes to the success of this project to the same extent that the Army's effort contributes to theirs. The criteria developed is incorporated in Military Standards for use in Development of Military Equipment for the overall Department of Defense. An example is DoD Project #MISC 0100, which is distributed throughout Department of Defense for coordination. Another example is the recent tri-service coordination of DoD MIL-STD 810 on "Environmental Test Methods for Military Equipment."

In addition, our work is complimentary to, and we have mutual interest in, the following national and international standardization activities:

(1) American Standards Association Sectional Committee Z84 on "Environmental Glossary."

(2) Institute of Environmental Sciences Standards Committee Activities.

(3) Institute of Environmental Sciences Environmental Handbook Committee Activities.

(4) American Society of Testing Materials various environmental subcommittees.

(5) Society of Automotive Engineers Climatic Testing subcommittees.

(6) International Standards Organization (ISO) Environmental Standardization Committees and Working Groups.

Active coordination exists presently between the Institute of Environmental Sciences and the Department of the Army in connection with the preparation of the Army's proposed Environmental Handbook Series, presently being coordinated through AMCRD-RE and the U. S. Army Research Office-Durham (at Duke University).

Active cooperation also exists between the Army and the DoD Shock and Vibration Information Center, to which the work on this project is contributory and of vital mutual interest.

Coordination also exists between other military departments and government agencies, particularly the following:

Environmental Division, Directorate of Engineering Test, Air Force Systems Command, Wright-Patterson AFB, Ohio.

Quality Evaluation Laboratory, Bureau of Weapons, Naval Ammunition Depot, Crane, Ind.

Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, Md.

Atomic Energy Commission's Sandia Corp., Sandia Base, Albuquerque, N. M.

Aerospace Industries Association of America, Inc., Washington, D. C.

National Academy of Sciences, National Research Council, Washington, D. C.

U. S. National Committee of the International Electrotechnical Commission, New York, N. Y.

BIBLIOGRAPHY

1. Forde, Harold M., and Schierbrock, William N., "Determination of Significant Conditions of the Physical Environment for Military Research and Development," University of Denver, Department of Geography Technical Paper No. 64-5 (DDC No. AD 450594), Contract DA-31-124-AROD-79, Project "Duty," 1964.

2. Gossett, James L., and Harris, Robert A., "Formulating Analytical and Technical Estimates," U. S. Army Missile Command, Redstone Arsenal, Alabama (DDC No. AD 80913), 1966.

3. Marks, G., DoD "Environmental Guidance Program in the Environmental Field" (PDL-36462), (Filed: DDR&E, AMCRD-RE, and ARO/P&R), 1960.

4. "Report to the President on Government Contracting for Research and Development" (Bell Report), Senate Document No. 94, prepared by the Bureau of the Budget (U.S. Government Printing Office), 1962.

5. "Scientific and Technological Communication in the Government," Task Force Report to the President's Special Assistant for Science and Technology (U.S. Government Printing Office), 1962.

6. "Science, Government, and Information, The Responsibilities of the Technical Community and the Government in the Transfer of Information: A Report of the President's Science Advisory Committee," The White House, January 10, 1963 (U.S. Government Printing Office), 1963.

7. "Final Report on Scientific and Technical Information." Defense Science Board Sub-committee, Office of Defense Research and Engineering, Washington, D.C. 16 July 1963.

8. "Research in Progress, 1962;" Section IV, F, "Environmental Research," U. S. Army Research Office-Durham, Durham, N. C., 1962.

9. "Research and Technology Resume," DD Form 1498, Project 1V025001A622, 1966.

BIBLIOGRAPHY (Cont'd)

10. Minutes of First Ad Hoc Ordnance Corps Environmental Research Planning Conference, Detroit Arsenal (Filed AMCRD-RE), 1961.

11. Minutes of Last (28th) Meeting, Panel on Environmental Research, Army Committee on Environment, Detroit Arsenal (Filed AMCRD-RE, OCRD), 1962.

12. Minutes of Second Ad Hoc Ordnance Corps Environmental Research Planning Conference, OTAC, Detroit Arsenal (Filed AMCRD-RE), 1962.

13. Proceedings of Second Environmental Symposium, Keynote Speeches, "The Challenge," by Major General T. H. Lipscomb and Colonel G. F. Leist, at Southwest Research Institute, San Antonio, Texas, 1962.

14. AR 1-71, "Standardization among the Countries of the North Atlantic Treaty Organization," Hq, Department of the Army, Washington, D.C., 17 September 1964.

15. AR 11-20, "Army Cost Reduction Program," Hq, Department of the Army, Washington, D.C., 1 September 1965.

16. AR 11-25, "Army Programs, Reduction of Lead Time," Hq, Department of the Army, Washington, D.C., 27 September 1961.

17. AR 18-7, "Army Information and Data Systems, Data Processing Installation Management, Procedures, and Standards." Hq, Department of the Army, Washington, D.C., 29 September 1961.

18. AR 70-10, "Research and Development, Army Materiel Testing," Hq, Department of the Army, Washington, D.C., 18 December 1962.

19. AR 70-40, "Research and Development, U.S. Army Research Offices Overseas," Hq, Department of the Army, Washington, D.C. 15 May 1963.

BIBLIGRAPHY (Cont'd)

20. AR 70-42, "Research and Development, U.S. Army Research Office-Durham," Hq, Department of the Army, Washington, D.C., 22 April 1966.

21. AR 71-1, "Army Combat Developments," Hq, Department of the Army, Washington, D.C., 30 July 1962.

22. AR 705-5, "Research and Development of Materiel, Army Research and Development," Hq, Department of the Army, Washington, D.C., 14 January 1963, and Change 2, 1 June 1966.

23. AR 705-15, "Research and Development of Materiel, Operation of Materiel under Extreme Conditions of Environment," Hq, Department of the Army, Washington, D.C., 4 October 1962, and Change 1, 14 October 1963.

24. AR 705-25, Research and Development of Materiel, Reliability Program for Materiel and Equipment," Hq, Department of the Army, Washington D.C., 8 January 1963.

25. AR 705-26, "Research and Development of Materiel, Maintainability Program for Materiel and Equipment," Hq, Department of the Army, 16 April 1963.

26. AR 705-55, "Research and Development of Materiel, Managements of U. S. Army Research and Development Laboratories or Activities," Hq, Department of the Army, Washington, D.C., 11 October 1962.

27. AR 715-50, "Procurement, Materiel Standardization," Hq, Department of the Army, Washington, D.C., 30 July 1962.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) FRANKFORD ARSENAL, Philadelphia, Pa. 19137 SMUFA L3300	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP NA

3. REPORT TITLE

ENVIRONMENTAL CRITERIA AND SIMULATION METHODS RESEARCH STUDY

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Research Report

5. AUTHOR(S) (First name, middle initial, last name)

SIMPSON, Maurice H.
ASKIN, David

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1967	40	27 (Bibliography)

8a. CONTRACT OR GRANT NO. AMCMS Code 5027.11.701 b. PROJECT NO. DA Project No. 1V025001A622 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Frankford Arsenal Report R-1876 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	AMCRD-TV

13. ABSTRACT The primary function of development and testing of Army materiel is to ensure that material scheduled for worldwide use satisfies minimum operational, technical, and safety requirements in all types of environments and troop operational employment. Accordingly, design and test criteria must provide factual bases for technical doctrine to supp ·r operational objectives and improved combat capability.

nis research program provides such factual bases. It does so by employing systems appro h and operations analyses techniques applied to a viable environmental situation to develop environmental criteria and simulation methods. A model is developed that is devoid of arbitrary factors and is, thereby, realistic to natural environments of field and storage (standby) operations. Systems concepts are used to encompass the effects of multi-environmental complexes. Artificial and psuedo-environmental concepts are removed so that better correlation of laboratory testing with field performance is made possible.

Fundamentally underlining this research approach is the concept that hardware failures are always symptomatic of disorder in a particular dynamic system. Emphasis is on the constructive method of research wherein it is considered that an event is always the result of an interaction of several coexisting factors, and that hazards are not haphazard but exhibit patterns that can be identified. The event is studied as a whole, then the operative factors are gradually sorted out by a series of increasingly precise approximations. Overall relationships are maintained intact, correctly placed in relationship with each other and held in contact, yet they are differentiated. The net result is an "up-and-down" picture of nature's environmental system and its effects on materiel performance, leading to development of realistic environmental criteria and simulation methods.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Environmental Criteria						
Environmental Effects						
Environmental Factors						
Environmental Information						
Environmental Predictions						
Environmental Simulation Methods						
Environmental Synergistic Effects						
Environmental Test Methods						
Interaction of Environmental Factors						
Operations Analysis						
Operations Research						
Reliability						